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Beaufort Sea pack ice break-up by long period swells

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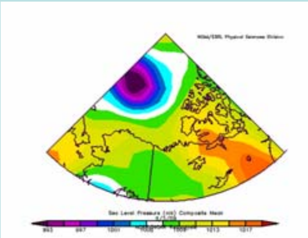


Low existed from Sept 2-4 directly north of Bering Strait at 82°N moving eastward.

Recently-broken second-year ice ridges (6-8m) seen from the icebreaker bridge on 06 September, 18:15 MDT.

During the summer of 2009, ice observations were being made with a helicopter stationed on the CCGS Amundsen, while she traversed the Canadian Beaufort Sea pack ice from 28 August to 12 September (Fig, 1). The ice encountered was made up of thin "rotten" first-year ice (50-75cm thick) (Fig. 2, 3), and thicker second-year ice (2-3m thick) that contained melt ponds (Fig. 2, 4). The ice did not represent an obstacle to the icebreaker, which moved at full speed along its planned track to station "L3", well above 75°N.

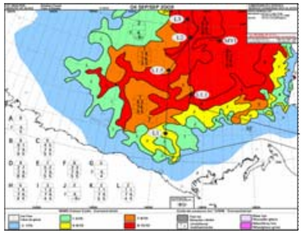


Figure 1. Beaufort Sea ice chart for 04 September 2009, produced by Canadian Ice Service with the Amundsen ship track overlain.

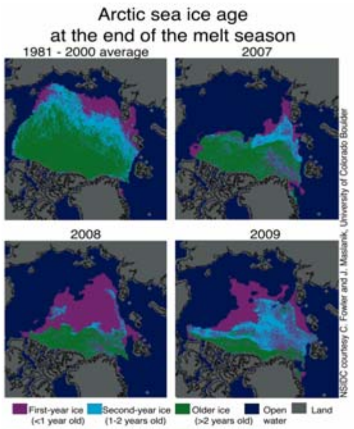


Figure 2. Arctic sea-ice age at the end of the melt season for 2007, 2008 and 2009 as compared to the mean of 1981-2000, National Snow and Ice Data Centre courtesy of C. Fowler and J. Maslanik.

Figure 3. The thinner and "rotten" first-year ice with black bottomless melt ponds.

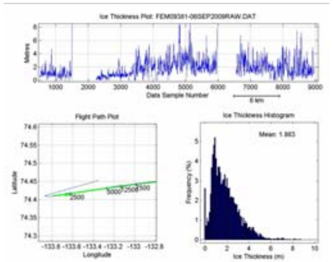
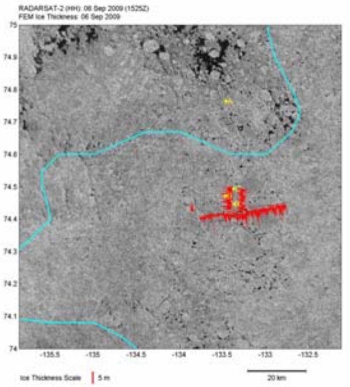


Figure 4. Ice thickness profile collected from west to east on 06 September 2009 (10:00-11:00 MDT) passing from mostly first-year ice to second-year ice at data sample #3500, where the icebreaker was stationed from 12:00-14:00 MDT (Figure 6).

Figure 5. The CCGS Amundsen anchored at station "MYI" (06 September 2009, 12:00 MDT) with mooring lines to a second-year ice floe (74.446°N, 133.37°W). The icebreaker was moved at ~14:00 MDT because of the heaving motion of the swell.

Figure 6. RADARSAT-2 SAR image from 06 September 2009 (1525 UTC), with ice thickness data in Fig. 4 overlain. The positions of the icebreaker on 06 September (12:00-14:00 MDT), and of the mosaics in Fig. 7, 8, and 9, are marked by X, A, B, and C respectively. The blue line shows the boundary between the concentrated (9+/10) ice region (right), and the less concentrated (9/10) ice region (left) in the CIS ice chart (© RADARSAT-2 Data and Products © MacDonald Dettweiler and Associates Ltd (2009) – All Rights Reserved).



Upon arriving at station "MYI" (Fig. 1, 5) within the thicker and more consolidated pack ice on 06 September (~12:00), long period swells appeared from the northwest, and continued for a day. The period of the swells was initially 14s, but decreased over time. Video frames were collected with a fix-mounted downward-looking video camera on the helicopter, and documented fractures in ice floes. A mosaic collected at 10:49 MDT (Fig. 7), shows linear fractures in first-year ice north of the icebreaker, while second-year ice around the icebreaker at 11:02 MDT is not fractured (Fig. 8). However, a mosaic collected at 13:32 MDT shows a second-year ice floe breaking up into smaller floes (Fig. 9).

Figure 7. Mosaic 57990 of thin first-year ice from 06 September (10:49 MDT) at 74.764°N, 133.469°W. The video frames are 135m wide, and were collected while flying from north to south (south is at top).

Figure 8. Mosaic 59360 of un-fractured second-year ice from 06 September (11:02 MDT) at 74.472°N and 133.472°W. The video frames are 140m wide, and were collected while flying from north to south (south is at top).

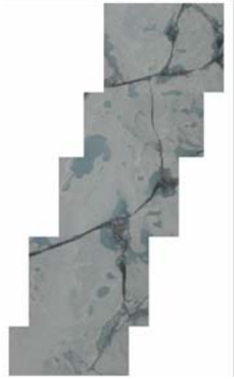


Figure 9. Mosaic 61270 of fractured second-year ice from 06 September (13:32 MDT) at 74.494°N and 133.375°W. The video frames are 135m wide, and were collected while flying from south to north (north is at top).

The swell wave packets were also seen in the high frequency ship sonar data (Figure 10), and may account for fluctuations in the laser data collected during a helicopter flight on 06 September (Figure 11). These data sets indicate a swell period of 14s and wavelength scales of 200-300m, in agreement with deep water wave theory and the frequency of the fractures seen in the mosaics.

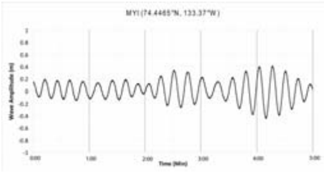


Figure 10. High frequency ship sonar data from 06 September (12:03 MDT) showing swell period of 14s and amplitude reaching 0.4m. (Ian Church, U. New Brunswick)

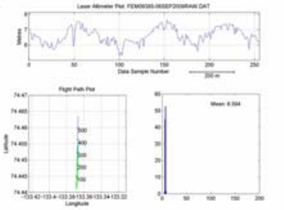


Figure 11. Helicopter laser data of 06 September (14:00 MDT) collected near the icebreaker; fluctuations may be due to swells.

Upon moving south to station L1.1, ice thickness and video data were collected on long flights due west (100km) and due east (60km) on 09 September. The pack ice was broken up everywhere, as seen in the hand-held camera pictures (Fig. 12, 13) taken at an altitude of 150m. The largest floes seen in Fig. 12 are in the 150m range, while Fig. 13 shows the limit to which the swells penetrated into the pack ice. Here the pack ice is broken up, but the pieces have not altered their relative positions. The darker first-year rotten ice can clearly be distinguished from the whiter second-year ice.

Figure 12. Broken-up pack ice on 09 September (11:22 MDT) at 72.518°N, 136.43°W.

Figure 13. Limit of northwest swell penetration into the pack ice, 09 September (11:04 MDT) at 72.526°N and 134.51°W.

Conclusion: Distant Arctic storms over open water can generate long period swells which penetrate and break up the pack ice without any ridging, as far as 250km into pack ice. In summer this will enhance the decay of the pack ice due to increased radiation input to the ocean, while in early winter it may enhance ice growth in the newly-formed leads.

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